Color Management for Snow Leopard

Session 301

These are confidential sessions—please refrain from streaming, blogging, or taking pictures.

At the convention center, a movie will be placed here

Color Management for Snow Leopard

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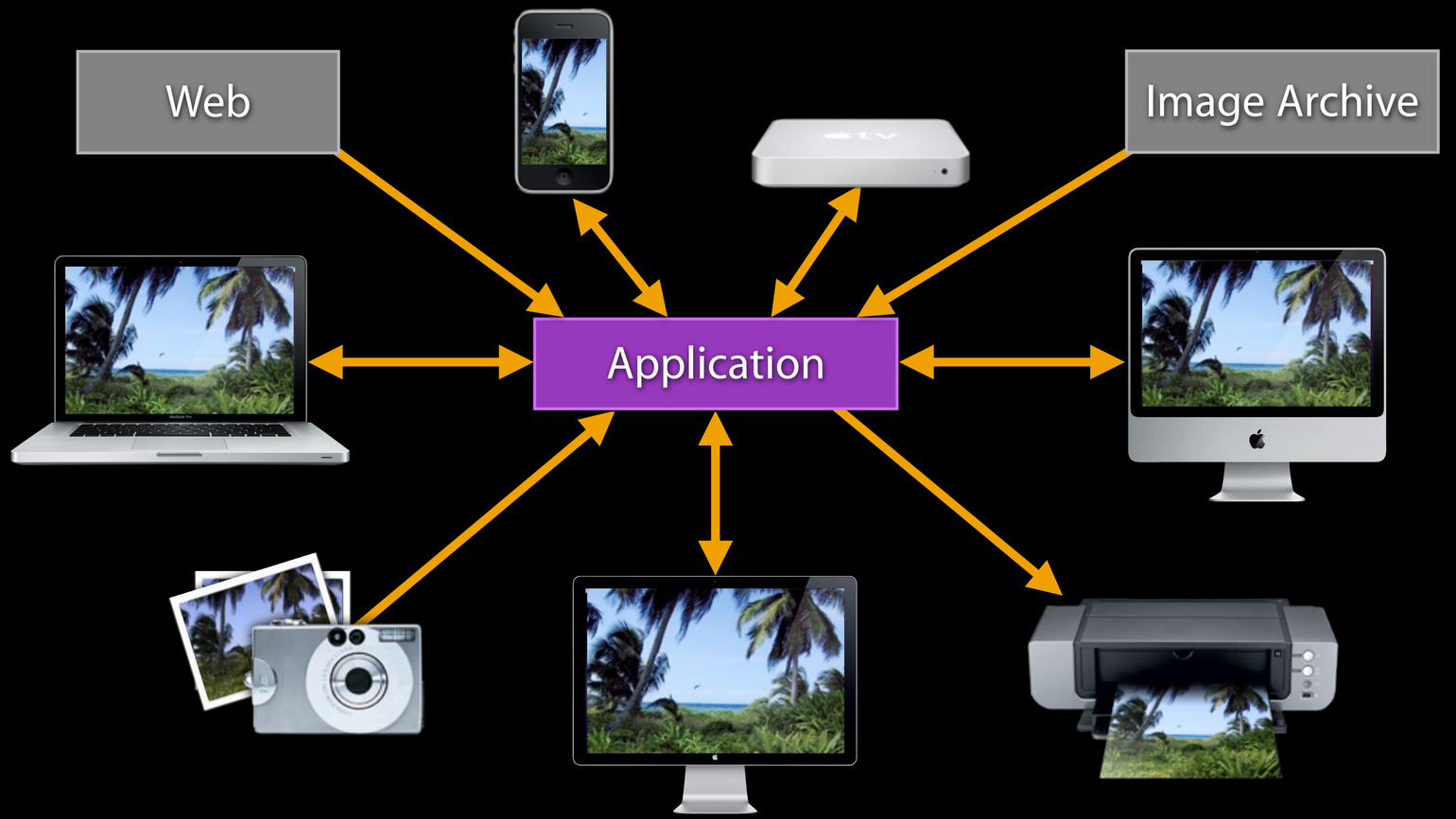
What You'll Learn

- Color Management Architecture in Snow Leopard
- New ColorSync API
- Changes to system gamma
- Window Backing Store Color Space
- Video Color Management in QuickTime X

Color Management Workflows

Consistent color appearance across different devices



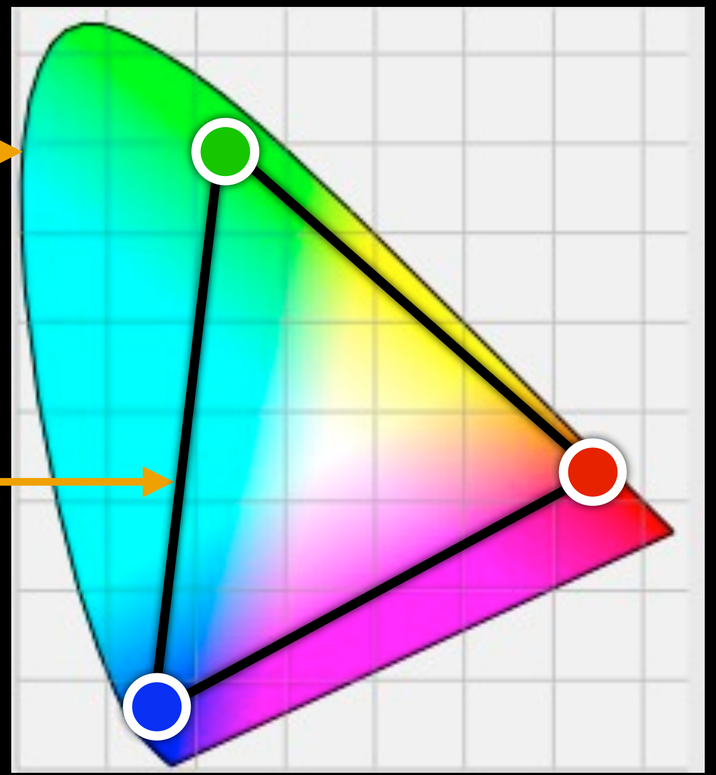
Color Management = Controlled conversion between different color representation

Device Color Capabilities

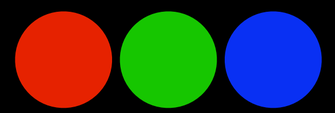
Device Gamut

Visible spectrum

Gamut boundary



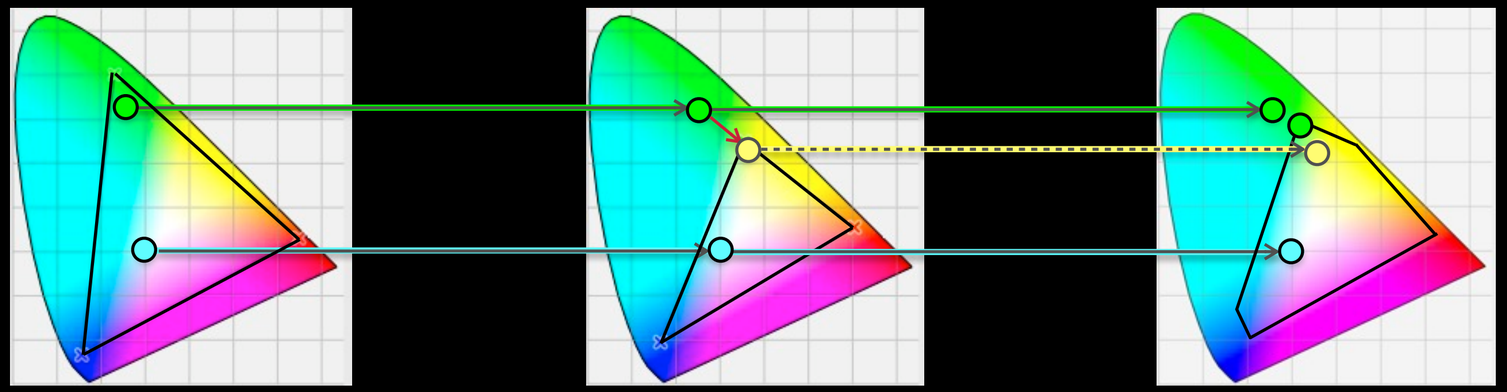
Primaries



Adobe RGB—typical color space of a digital SLR camera

Problem to Solve

Reproducing color on different devices



Adobe RGB camera

Laptop Display

Inkjet Printer

- in gamut, no color shift

- in gamut, no color shift

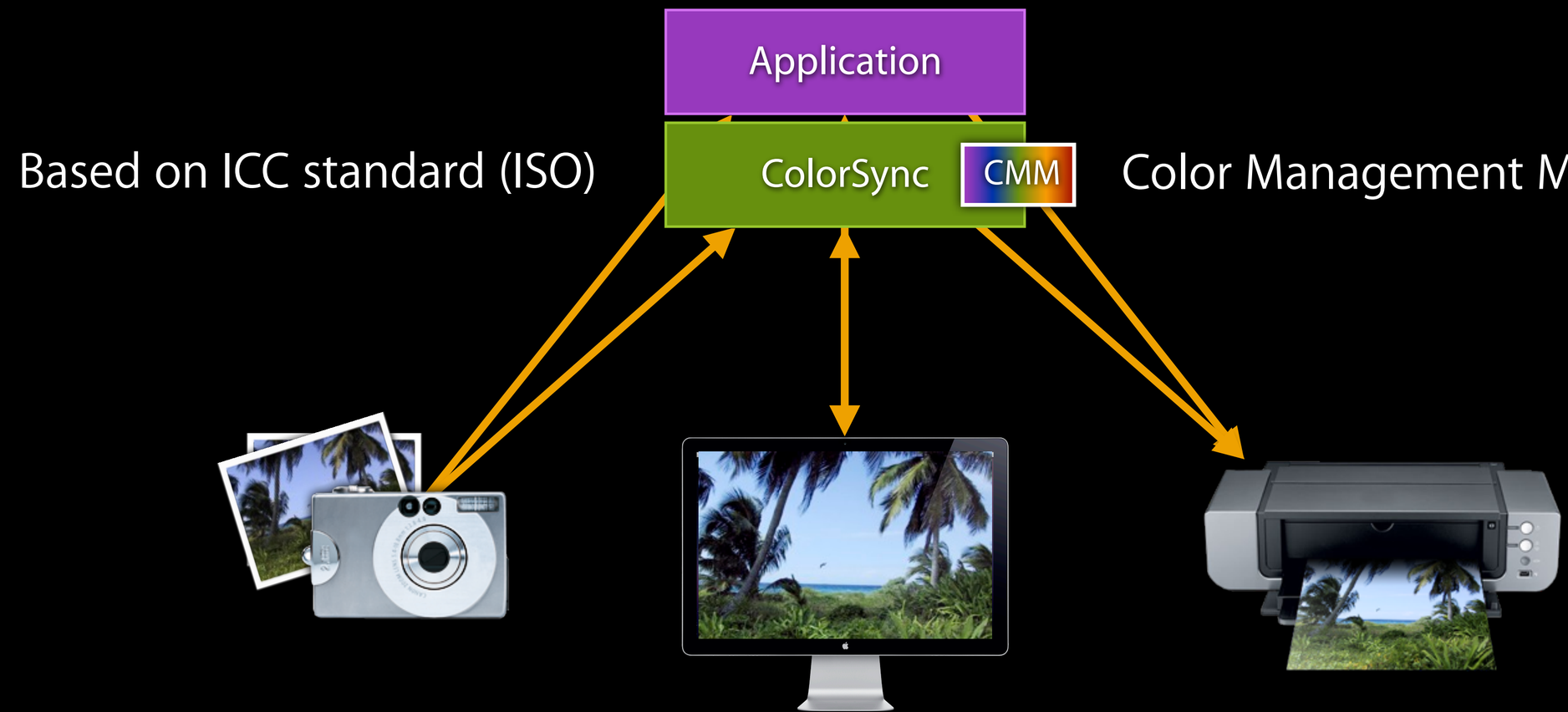
- significant color shift, different appearance

- small color shift, similar appearance

- conversion to a smaller color gamut can cause irreversible damage

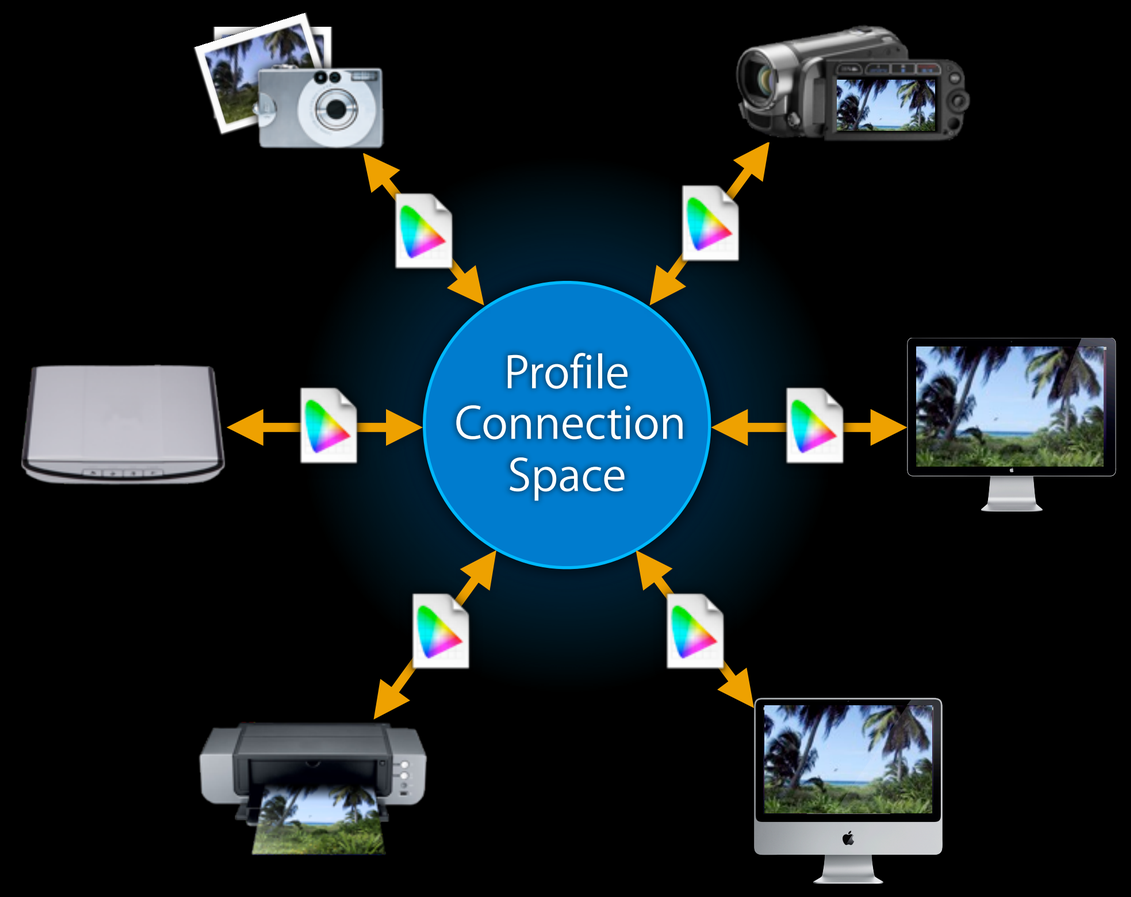
Integrated Automatic Color Management

Color Management Technology provided by ColorSync



How Does It Work?

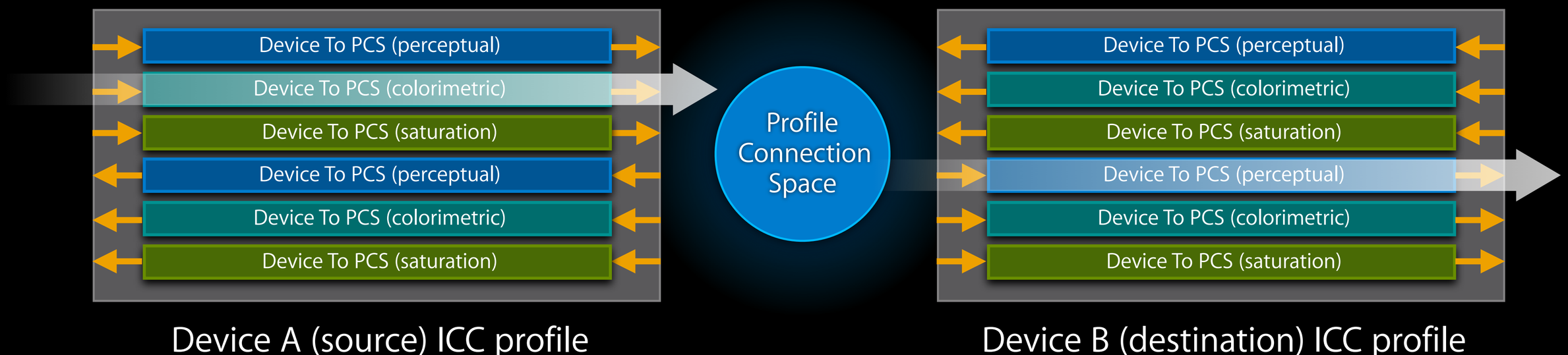
- Profiles contain tags that describe how to convert data between device color space and a reference color space called Profile Connection Space



More Details…

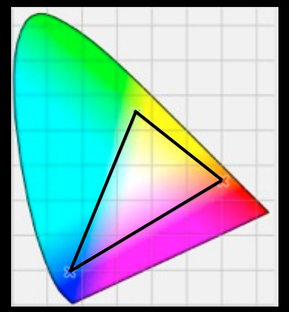
Creating Color Transform

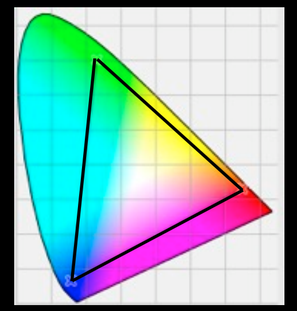
- Profiles may contain different tags for different rendering intents
  - Perceptual, colorimetric and saturation
- CMM creates transform from profile tags based on rendering intent and type (i.e. device color space to PCS or PCS to device color space)
- CMM converts 8-bit integer, 16-bit integer and 32-bit float data



Color Conversion

Numerical example





Source = LCD Display Profile

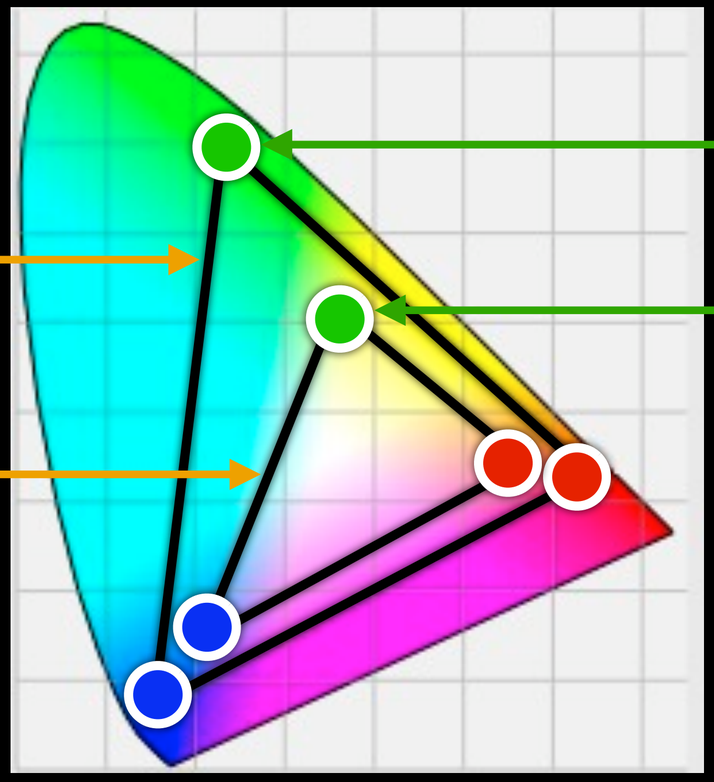
Destination = Adobe RGB profile

Color in Perspective

Device Color Values vs. Calibrated Color Values

Adobe RGB

LCD Display



8-bit RGB values in Adobe RGB = {0, 255, 0}

8-bit RGB values in LCD Display = {0, 255, 0}

LCD Display {0, 255, 0} = {158, 229, 76} in Adobe RGB

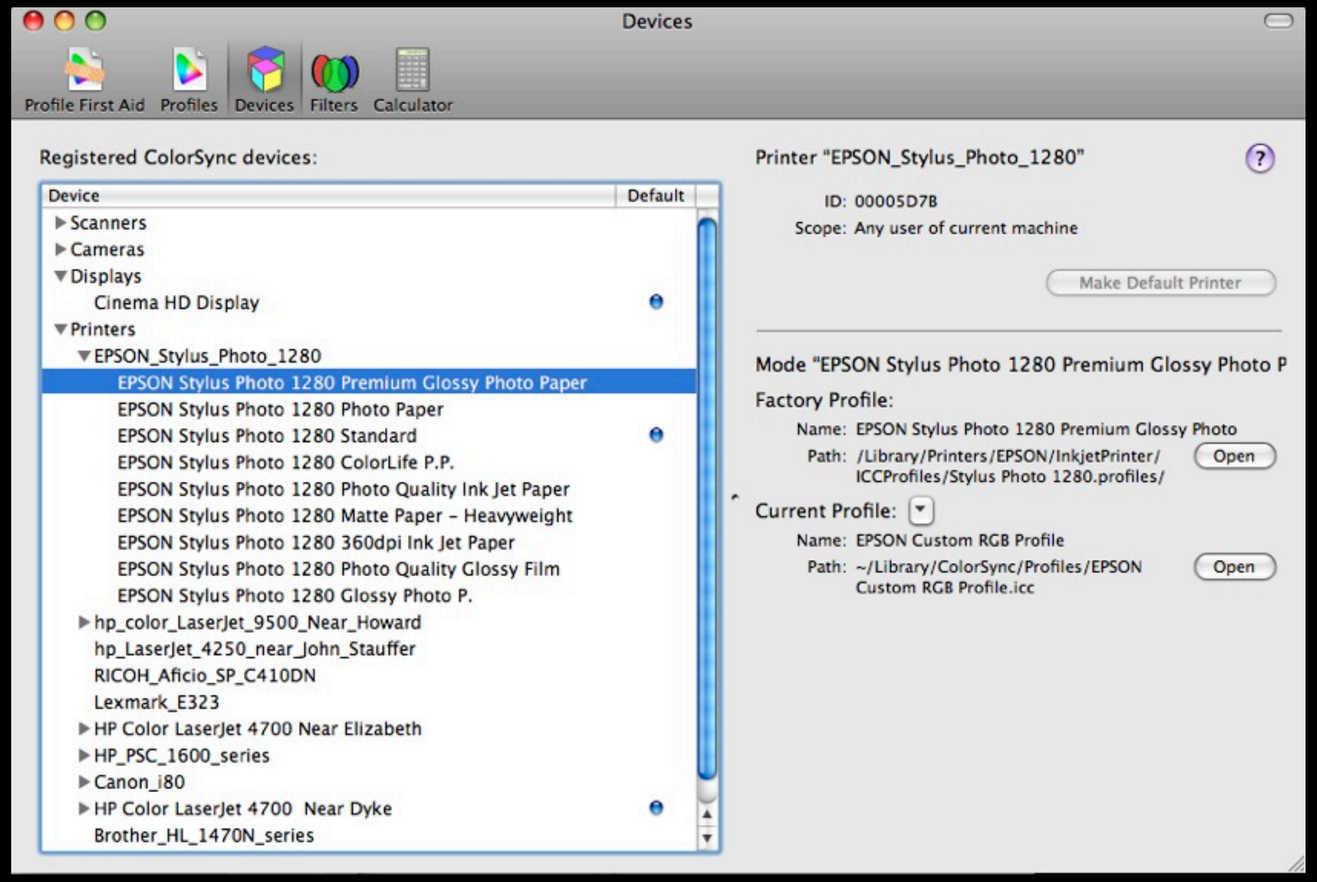
Color values will be unequivocal only if they are tagged with proper profile!

Device Integration

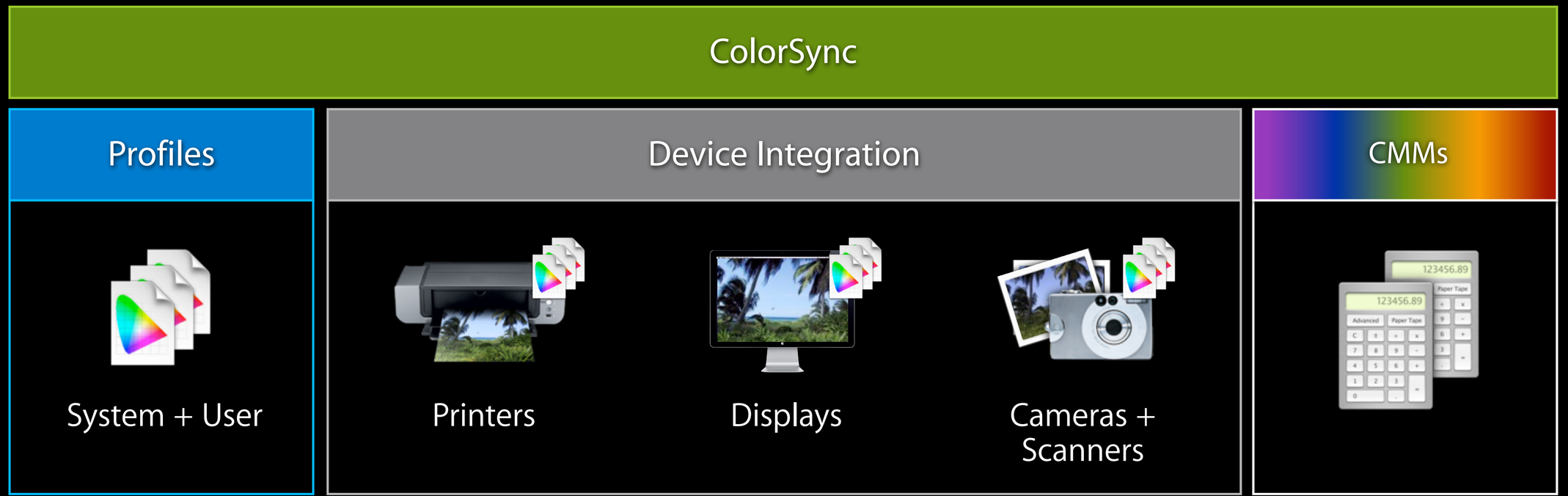
- Mac OS X has Device Managers for input, display and printing
- Device Managers are integrated with ColorSync
  - Provide awareness of devices and access to their profiles
- Device and Profile Registration
  - Device Managers detect presence of devices
  - Register profiles provided by device drivers (factory profiles)
  - Can also build device, e.g. Display profiles based on EDID
- Device Integration services include notifications

Device Profile Overriding

- User can access Device Integration database and assign profiles to color devices (custom profiles)

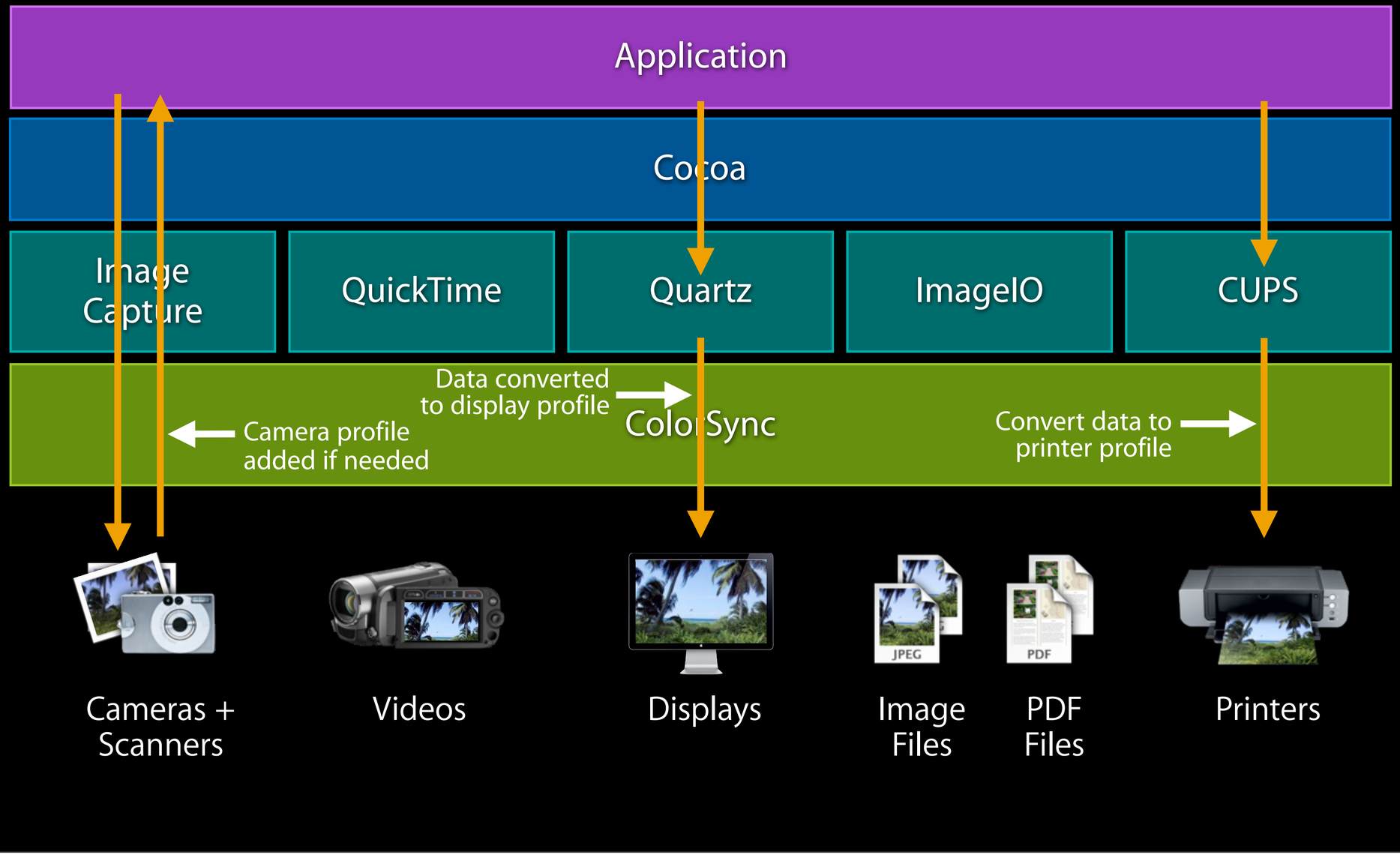


ColorSync Summary



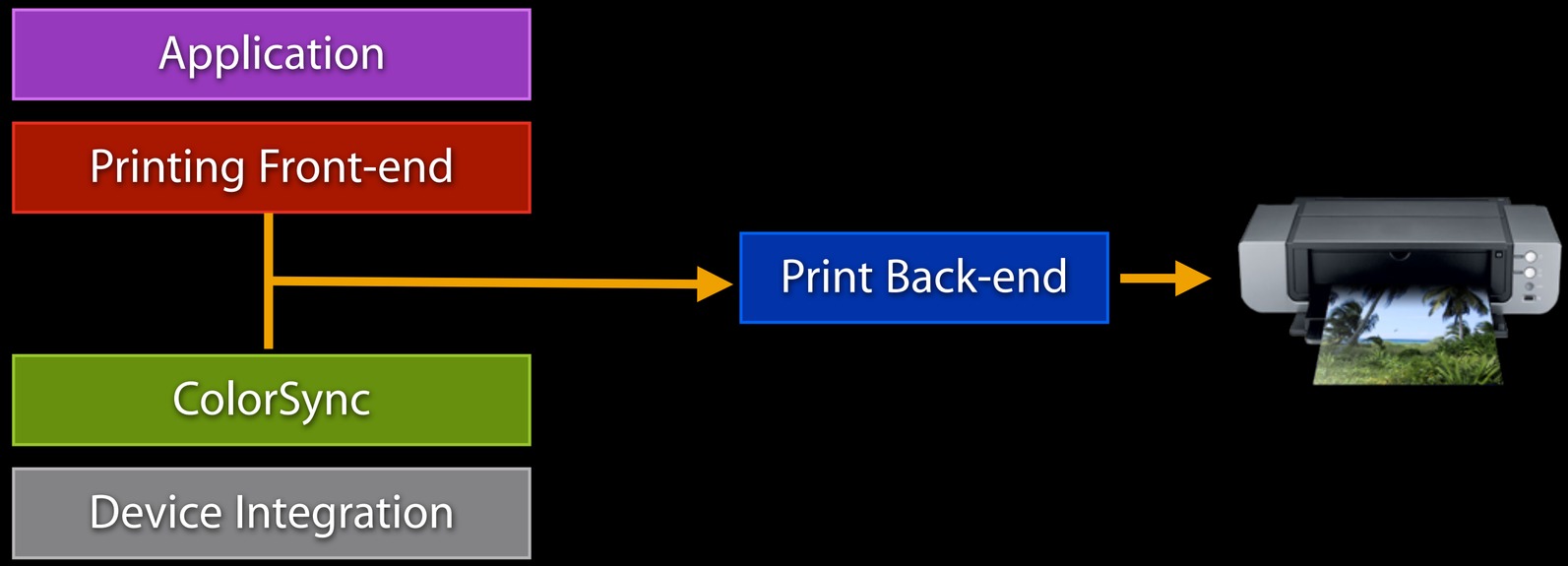
What Happens in the Application

Architectural overview



Mac OS X Printing Architecture

Architectural overview



- Printing Back-end may work in two modes
  - Color Handoff to the driver
    - All colors matched to the handoff color space e.g. sRGB
    - Driver applies custom color adjustment
  - Color is prematched using printer profile (driver makes no adjustments)

Color Management Architecture Summary

Take-away points

- Mac OS X offers integrated automatic color management
  - Profiles embedded in the data will be always used
  - When creating color data use well defined color spaces and don’t worry about the rest…
  - System will do full color management for you

New ColorSync API

For those who really need to know the details

- CoreFoundation-based, C API
  - 32 functions (replace 129 functions in old, deprecated API)
  - Sample code will be available for download

Leveraging GPU for Color Conversion

Upload color transform to GPU

- New ColorSync API
  - Provide a “recipe” (generalized code fragment) for color transform
  - Used by Core Image and QuickTime X to write fragment code in shader language uploaded to GPU

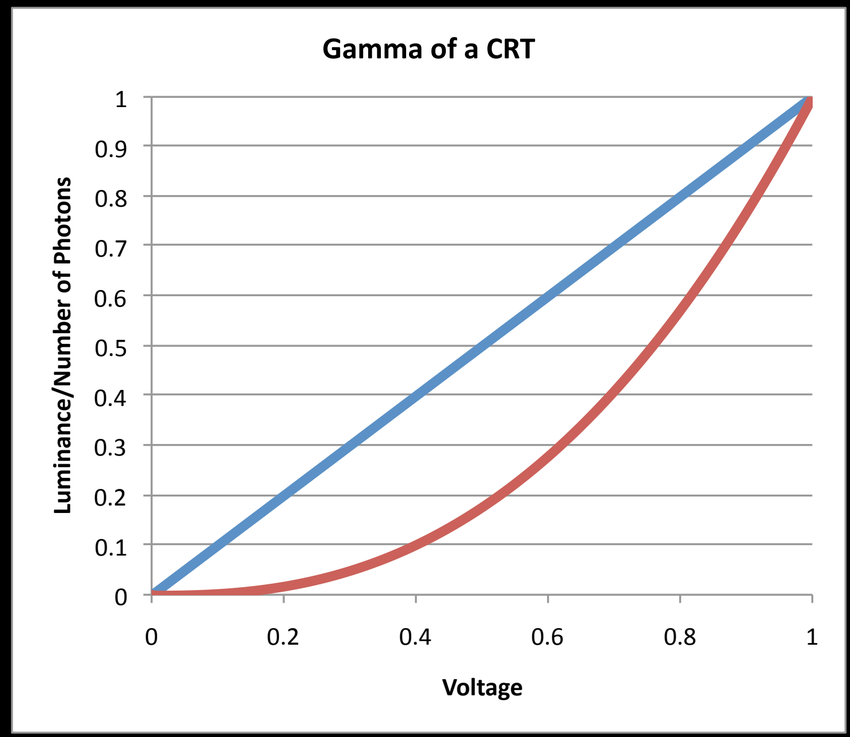
What's New in Snow Leopard

Advanced imaging topics

- New 2.2 system gamma
- Window Backing Store Color Space
- Display Change Notification

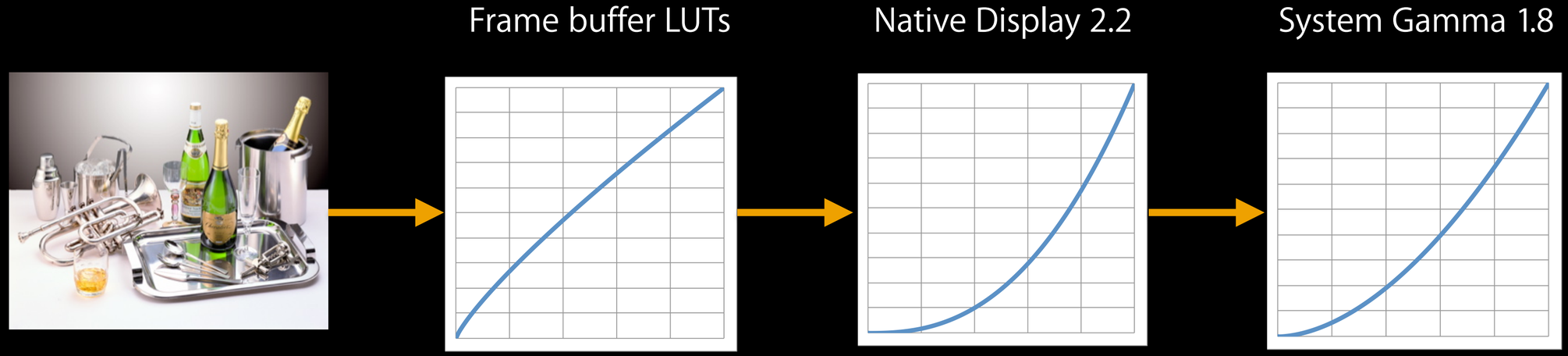
Changing System Gamma in Snow Leopard

- What is gamma?
  - Relationship between digital counts or voltages and luminance
    - Effective gamma of most CRTs is 2.2
    - LCD displays are built to behave as CRTs for backward compatibility



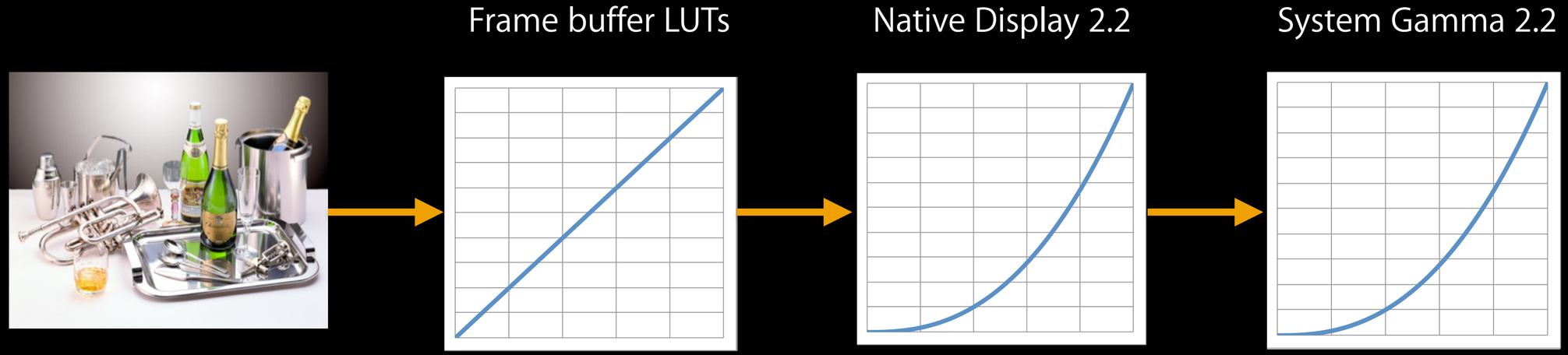
Traditional Mac Gamma

- Traditional Mac gamma is 1.8
  - Beneficial in the old days of printing without color management



Snow Leopard Gamma Is 2.2

- New Mac gamma beginning from Snow Leopard is 2.2
  - Aligned with standards for digital photography, digital video and web publishing



What to Do About Gamma Change?

- Color data tagged with profiles needs no change

1.8 gamma

=

2.2 gamma

What to Do About Gamma Change?

- Untagged (device) color data should be adjusted for display

1.8 gamma

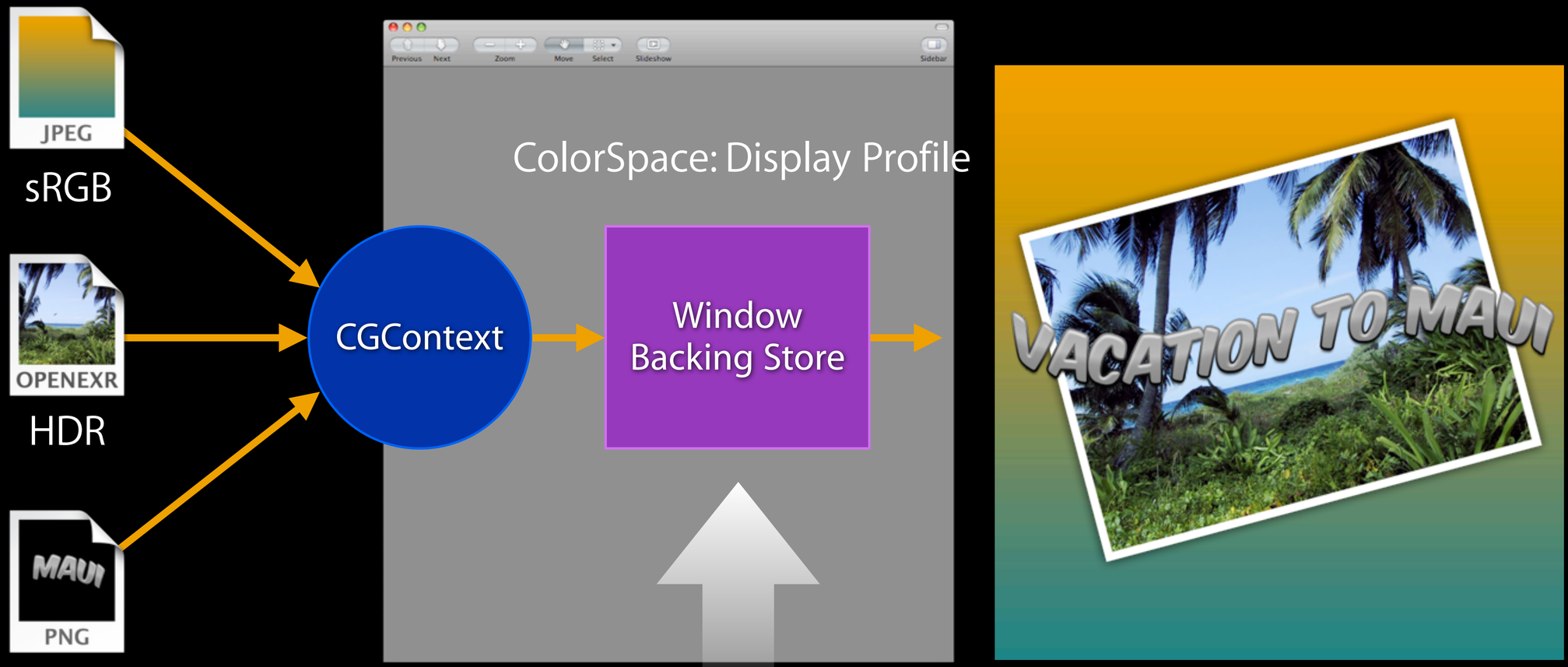
≠

2.2 gamma

What to Do About Gamma Change?

- ColorSync provides API to estimate display gamma
  - ColorSyncProfileEstimateGammaWithDisplayID (…)
- Untagged RGB data will be printed with 2.2 gamma
  - RGB data as sRGB
  - Gray data as Generic Gray 2.2 Gamma

Window Backing Store Color Space



New in Snow Leopard

Window Backing Store Color Space can be set by the application to any arbitrary matrix based RGB profile, e.g. sRGB, Adobe RGB, etc…

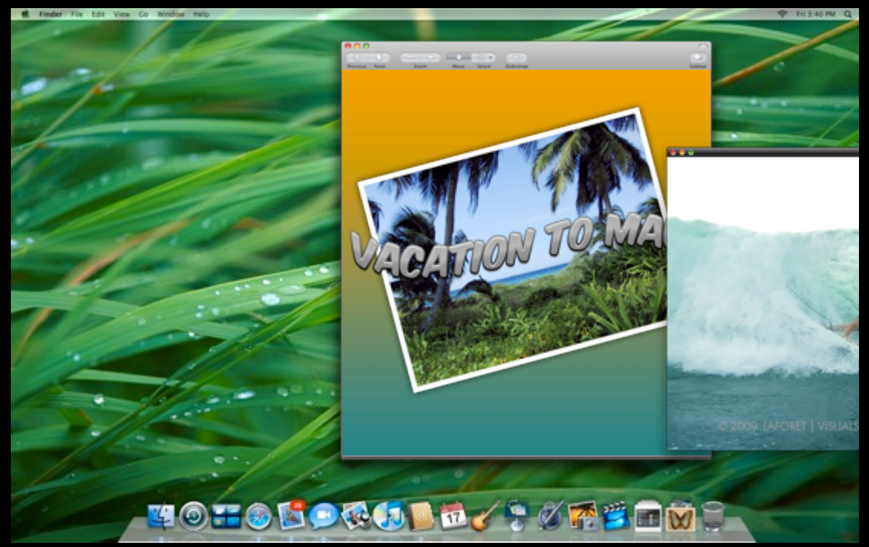
Window Backing Store Color Space

- Color correction of windows and surfaces to the display color space is GPU based and provided by Window Server
- Color data depth determined by the depth of the display (i.e. 8, 16, float)
- Work seamlessly within the Window System
- OpenGL applications
  - The rendered bits must be in the color space of the surface
    - Either do explicit color management, or use a fixed color space
    - Color management can be performed in GPU

Window Backing Store Color Space

- AppKit APIs
  - See Tech note
- Carbon APIs
  - See Tech note

Display Change Notification



Main Display

Secondary Display

Color Managed Video in QuickTime X

Ken Greenebaum
QuickTime Engineering

Color Managed Video in QuickTime X

- Interpreting video (from a computer perspective)
- What does it mean to color manage video?
- What's new for QuickTime X
- Implications of the new Gamma 2.2 display profile
- Evaluating an application's color/gamma

Interpreting Video from the Computer Perspective

Color TV Is an 1950s Era Technology

- With 1950s era solutions
- Video standards codify these practices
  - Tube based video material
  - Viewed on dim CRTs
  - In dimly lit living rooms

Tube Based Cameras

- Noisy in the dark regions
- Solution
  - Slope limit blacks
  - (rec.709 piecewise transfer fn)

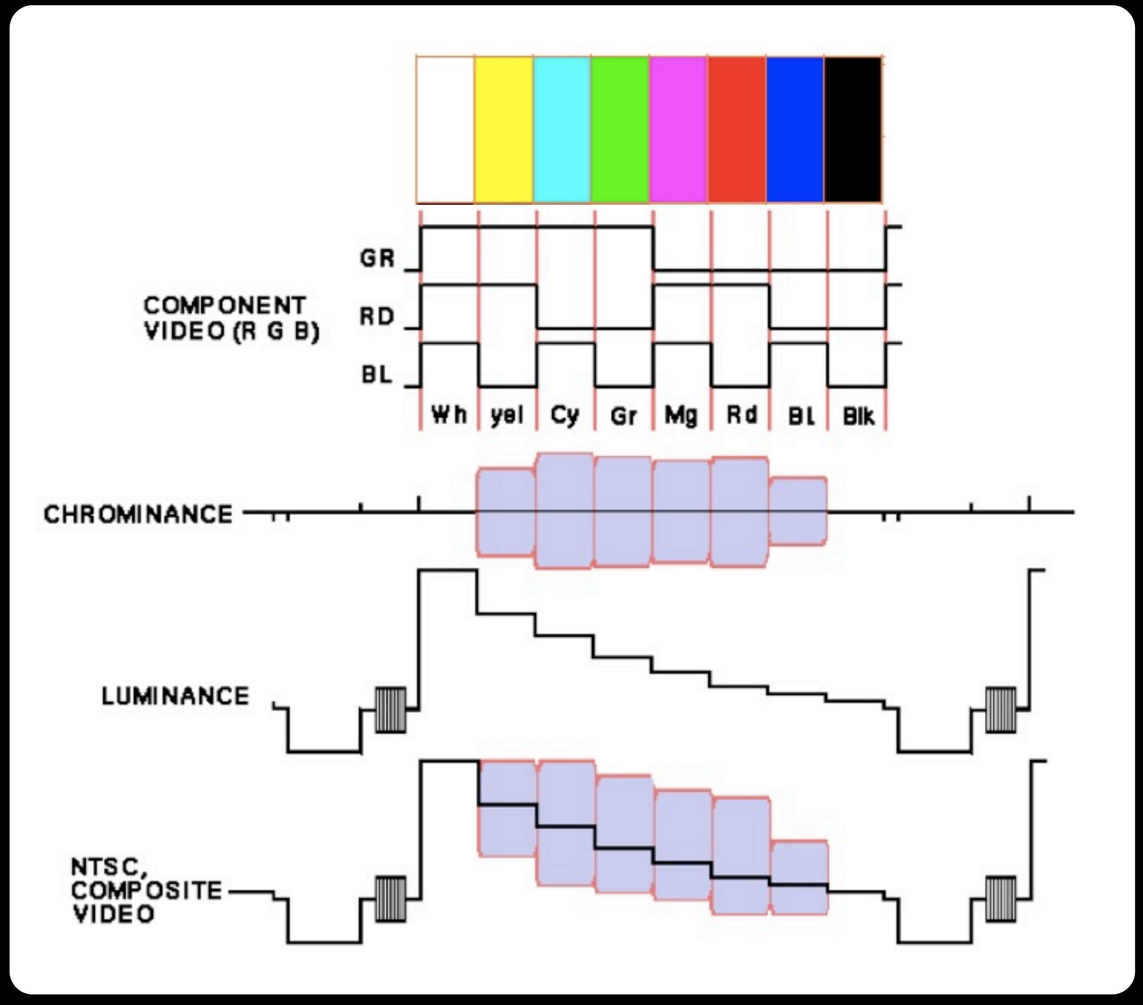
Dim Displays in Dimly Lit (Evening) Living Rooms

- ‘Dim-surround’ makes images appear flat
- Solution: Over unity gamma
  - Camera and TV Receivers are designed to provide approximately 1.25 boost

- Consider slide film
  - Projected in the dark
  - 1.5 gamma boost

Adding Color to B/W Signal

- TV originally B/W
  - Add color compatible with existing TVs
- Solution
  - Add reduced bandwidth chroma to existing luma
  - Early example of lossy compression!



SD Digital Video Standardized in the 1980s

- Defined
  - Sampling of analog lines to discrete pixels
  - Y’CbCr Luma/Chroma representation
  - 4:2:2 chroma subsampling
    - Cb, Cr chroma channels sampled at 1/2 the rate of the luma channel

SD Digital Video Standardized in the 1980s

- Other aspects left implicit
  - Gamma/Colorimetry
- Consider a DVD player
  - Doesn’t process luma/color
  - Just decodes MPEG2 and outputs signal
  - Sends results to TV to ‘interpret’
  - Pixel buffer implicitly at ‘video’ gamma

Mac Environment Is Different from DVD Player

- System is color managed for viewing environment
  - (Calibration is built into the display profile)
  - No extra gamma boost required or desired
- Display buffer not at nominal ‘video’ gamma
  - Snow Leopard 2.2 gamma
    - (Previously 1.8 gamma)

Gamma Correction from ‘Video’ Gamma to Display Gamma

- Requires interpreting ‘video’ gamma
  - We use a value of approximately 1.96
  - Derivations
    - 2.4–2.5 gamma of CRT with the 1.25 gamma boost removed
    - Gamma function with same area (tonality) as the suggested camera transfer function

Color Managed Video

What does it mean?

Color Managed Video

- Same motivation as 2D
  - Hi-fidelity reproduction of author's intent
  - Consistent authoring/display (across wide range of devices)
  - Author (even without broadcast monitor)
- Tag color intention with different tags
  - Video tagged with 'nclc'
  - (Still images are tagged with ICC Profile)

‘nclc’ a Structured Way to Tag Video Color

- ‘shorthand’ way to describe video colorimetry

1-1-1	HD (rec.709)
6-1-6	SD (SMPTE-C)
5-1-6	SD (PAL)

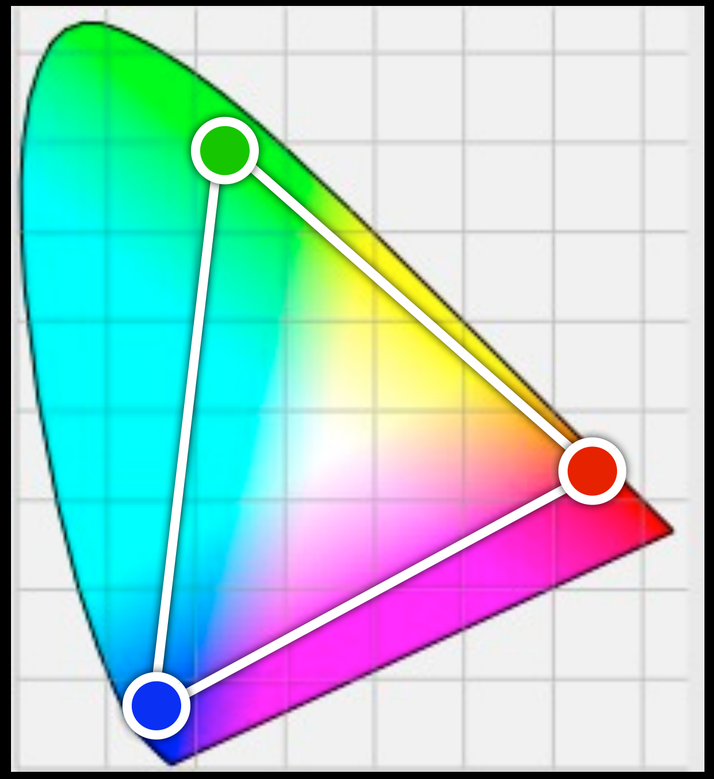
- ‘nclc’ may be found
  - Tagged in .mov, .mp4 wrapper (image description extension)
  - QuickTime Movie structure

- Defines three key video parameters
  - Primaries—Transfer Function—Conversion Matrix
  - Each are indices (not actual values)

Primaries: ‘nclc’ Parameter 1

- Examples

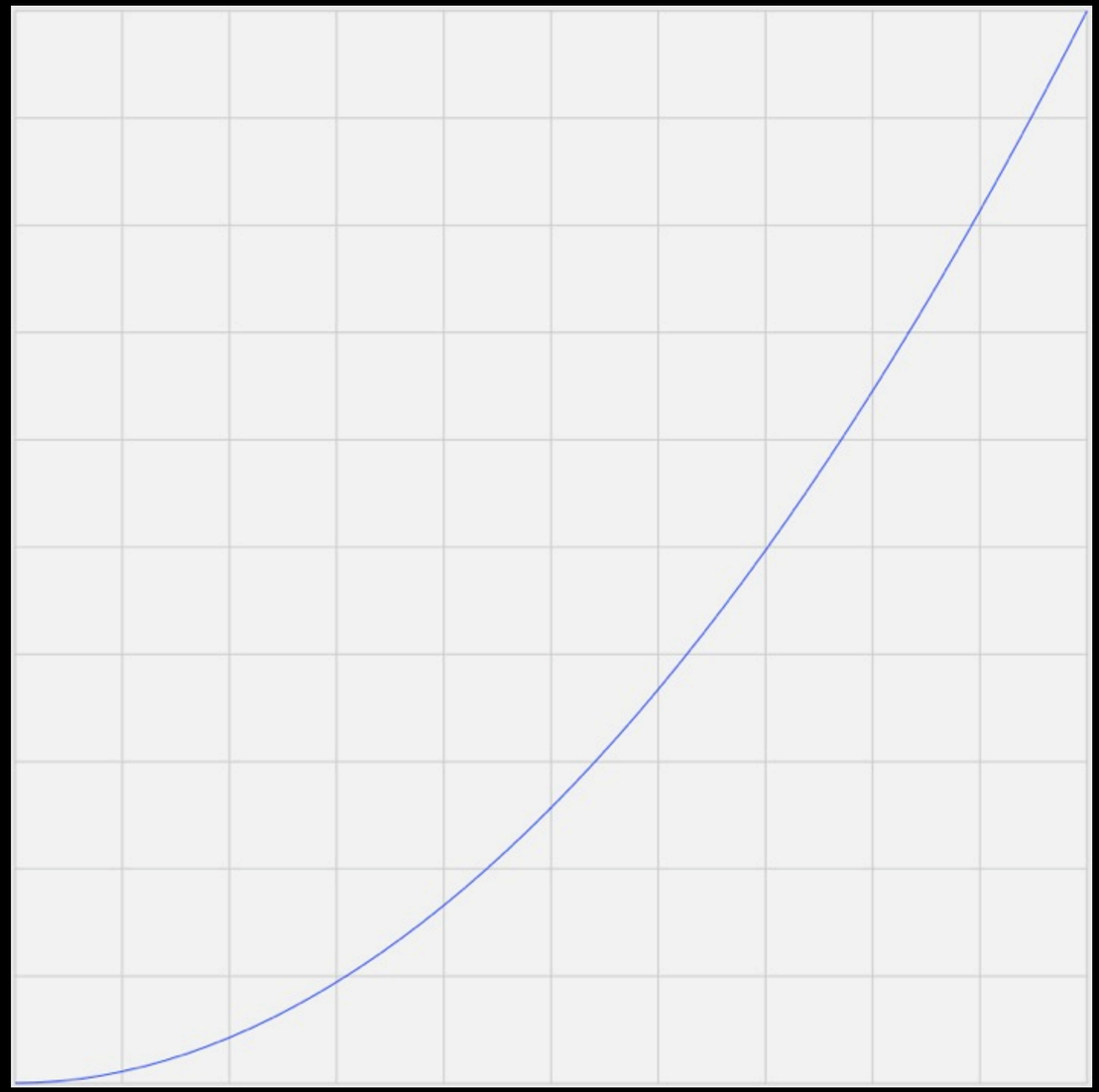
1	HD (rec.709)
5	SD (PAL)
6	SD (SMPTE-C)



Transfer Function: ‘nclc’ Parameter 2

- Sometimes called gamma
- Commonly only one value used

1	HD (rec.709 transfer function)



Matrix: ‘nclc’ Parameter 3

- Colorspace conversion matrix
  - Converts between Y’CbCr and R’G’B
  - Different matrix for each set of primaries

    $Y'CbCr_{rec.709}$ <--> $R'G'B_{rec.709}$

    $Y'CbCr_{SMPTE\text{-}C}$ <--> $R'G'B_{SMPTE\text{-}C}$
  - …

- Common Values

1	HD (rec.709)
6	SD (SMPTE-C)

QuickTime X

What is new in color management?

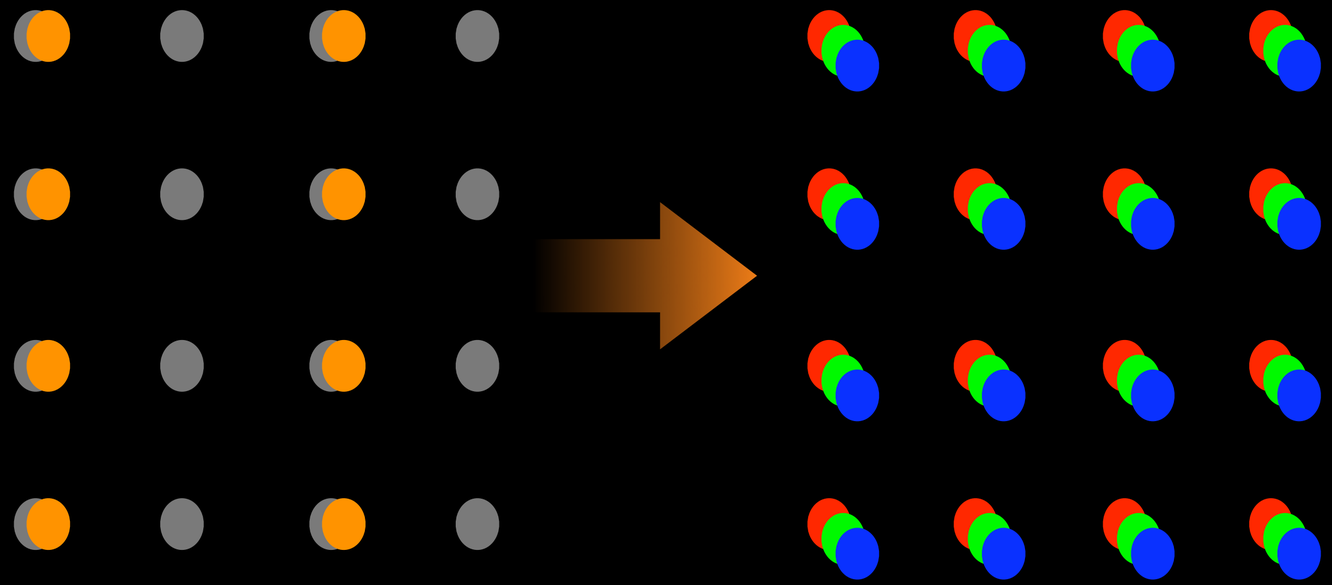
QuickTime X Color Management

- Display pipeline (GPU accelerated)
  - Color Management
  - Chroma siting based up-sampling to 4:4:4
- Colorimetrically correct
  - Export
  - Capture (from camera)
  - Screen capture
- Now color manages untagged content
- ‘nclc’ Tagging tool (automator action)
- Consistent color management across platform

GPU Accelerated Color Managed Video

- Steps for display
  - Up-sampling of subsampled Y'CbCr to 4:4:4
    - 'chrm' tag specifies chroma siting
  - Conversion to R'G'B' via specified matrix
  - Color-match and gamma conversion to display
    - 'nclc' tag specifies the video's primaries and transfer function

Chroma Siting Up-sampling



Y’CbCr 4:2:2
(center siting)

RGB 4:4:4

Colorimetrically Correct Export

- Color match (as required) to preserve author's intention
- Examples
  - Export to Apple TV
    - Apple TV is color managed
      - No conversion needed
  - Export to iPod/iPhone
    - iPod is SMPTE-C device
      - rec.709 to SMPTE-C color match is performed
      - Result is encoded using SMPTE-C matrix

Colorimetrically Correct Capture from Camera

- QuickTime X's capture architecture tags video with 'nclc'
- These video frames can then be
  - Previewed to the display, correctly, via colorsync
  - Compressed and Exported using appropriate processing
    - Matrix
    - Color Conversion
    - Resulting movie correctly tagged for future viewing

Colorimetrically Correct Screen Capture

- Pixels in display buffer are in Display's color space
- Not a classic video space
  - No appropriate 'nclc'
  - No appropriate RGB to Y'CbCr conversion matrix available
- Solution

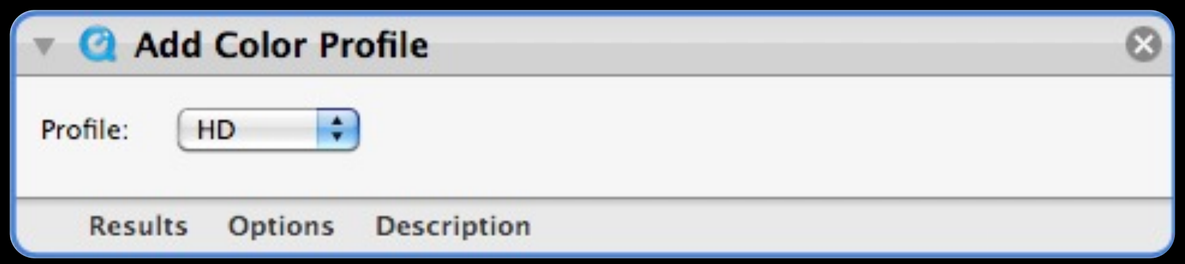
  ColorSync is used to convert $RGB_{display}$ to $RGB_{rec.709}$
  - Color Conversion
  - Gamma Correction
  - Result is true HD video than can be consistently processed and displayed

QuickTime X Color Manages Untagged Content

- Untagged content treated as ‘classic’ SD (6-1-6)
  - Display and export
- Consistent
  - No heuristics!
- True for all ‘modern’ media
  - h.264, etc.
  - QuickTime X falls back to QuickTime 7 for legacy content/modes
    - (QuickTime 7 Player always uses QuickTime 7 Pipeline)

‘nclc’ Tagging Tool

- New Automator Action makes it easy to tag video content
  - Old untagged content
  - (External) untagged content
  - Incorrectly tagged content



Consistent Color Management of Video Across Platform

- QuickTime X
- DVD Player
- i-Apps
  - iMovie, iTunes …
- Third-party apps using QuickTime

Implications of Gamma 2.2

Implications of Gamma 2.2 on Modern QT Apps

- NO IMPACT
  - QuickTime Visual context applications, QTKit
    - Have always been color managed
  - On Snow Leopard
    - Are color matched to the new 2.2 display gamma
    - (Consequently appear the same)

Leopard 1.8

Snow Leopard 2.2

Implications of Gamma 2.2 on Classic Video Apps

- NO IMPACT
  - Classic QuickTime Carbon GWorld/QuickDraw apps
    - Have never been color matched
    - They still aren't
- On Snow Leopard's 2.2 display gamma
  - They will appear darker
  - Same behavior as all Carbon apps

Leopard 1.8

Snow Leopard 2.2

Evaluating an Application's Color/Gamma

Things to Know/Remember

- In color managed applications
  - Pixel values are changed by the color match
    - On the way to the display buffer
    - Dependent on the display's icc profile
  - Resulting pixel values are likely different between monitors
    - Even if the monitors appear to be the same model

Evaluate Your Application Using Color Bars

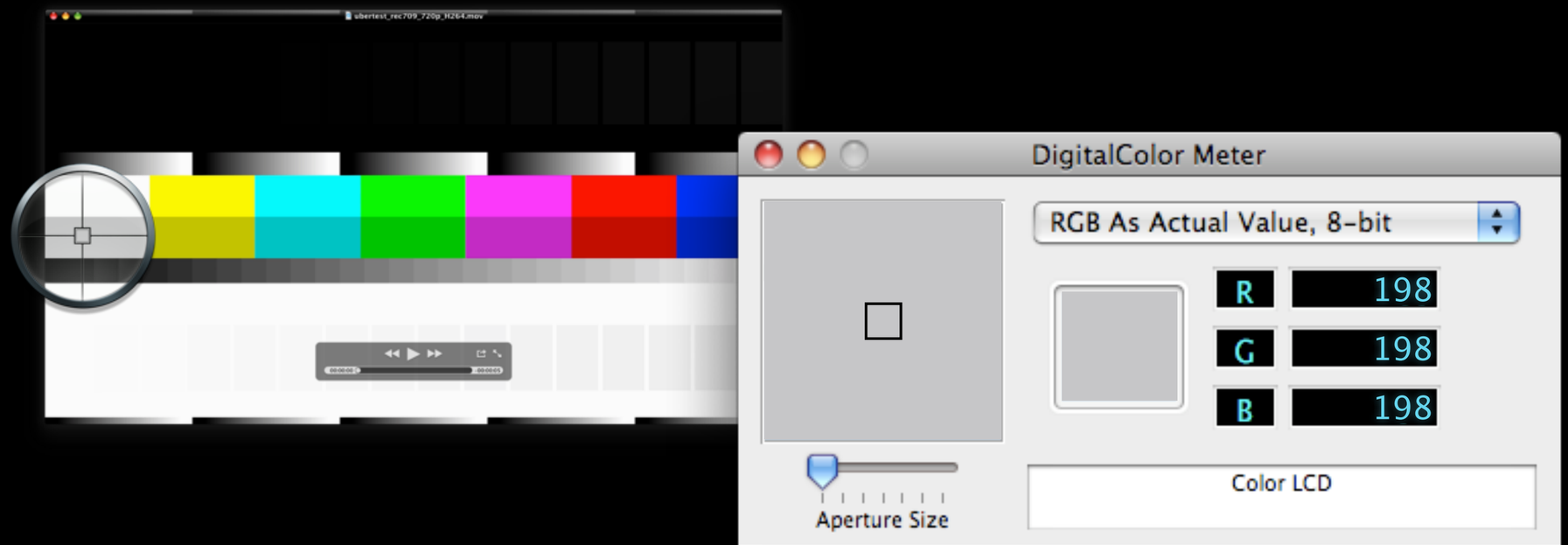
- SMPTE Bars are colorspace specific (ie rec.709, SMPTE-C, etc.)
  - Must be ‘nclc’ tagged to be correct
  - Thus applying the proper matrix
- 75% Bars have 191 (8-bit) energy levels in RGB
- Color match will
  - Keep grey levels ‘pure’ grey (all components equal)
    - No ‘color’ introduced
    - But will gamma correct
  - Change color values to make them appear correct
    - ex: 75% green
      - 0, 191, 0 -> 40, 200, 8

Experts Only

Interpreting 75% White Levels

- Possible displayed values and scenarios

198, 198, 198	1.96->2.2	Default QT X on Snow Leopard
186, 186, 186	1.96->1.8	Default QT 7 on Leopard and earlier
179, 179, 179	2.2->1.8	Classic QT, Final Cut, QT 7 untagged
191, 191, 191	2.2->2.2 or NOP	The RGB values encoded in the file



Experts Only

Conclusion

Take Aways

- Ensure all content is tagged with ‘nclc’
  - Use the new tagging automator action
- Untagged content is color managed
  - Treated as SD (6-1-6)
- Video is processed consistently on the platform
  - Across modern applications

More Information

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Labs

Color Management Lab	Graphics and Media Lab A Friday 12:00PM

Q&A

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